# FAA Milestone 2 Report for Inter-Agency Agreement DTFA01-02-X-02017

# Theoretically Acceptable Alternative NVIS Assessments

H. L. Task
A. R. Pinkus
August 31, 2002

AFRL/HECV
2255 H street
Wright-Patterson AFB, OH 45432-7022

## INTRODUCTION

This report is the second contractually required deliverable under the terms of the Interagency Agreement between the FAA and AFRL/HE. The purpose of this report is to describe and document possible alternative methods of assessing night vision imaging system (NVIS) lighting compatibility with night vision goggles (NVGs). Cockpit lighting can interfere with the proper operation of NVGs in several specific ways. In each interference mechanism the effect on the image seen through the NVGs is to reduce the light level or contrast of the useful image (the view outside the aircraft). This reduction in light level or contrast can be manifested as a reduction in visual acuity and/or as an observed loss of contrast or brightness. In order to better understand possible alternative methods of conducting NVIS lighting assessments, it is necessary to understand the currently accepted (baseline) method described in Mil Std 3009 (2001) and MIL-L-85762A, (1988). Since neither of these documents describes the currently used procedure in sufficient detail the technical report (Reising *et al*., 1995) is relied on to provide a more complete description.

## BASELINE ASSEMENT METHODOLOGY

Appendix A is a description of the baseline methodology used by AFRL/HEA to conduct NVIS lighting evaluations in the field. Since the joint FAA-AFRL research effort deals only with the evaluation of the lighting system with respect to interfering with the proper operation of the NVGs, only those sections of the AFRL/HEA procedures that deal with lighting interference are included. The other aspects of NVIS lighting evaluation, such as daylight readability and nighttime readability, are equally important in an overall NVIS evaluation but are not part of this research effort. Appendix B provides the NVIS evaluation procedures as described in Mil-Std-3009 and Appendix C provides excerpts from RTCA/DO-275 report describing NVIS evaluation procedures. Although these 3 documents vary somewhat they are all essentially based on Mil-L-85762A. The following is a summary of the elements of the baseline assessment methodology.

***Radiometric Measurement Equipment Baseline***

Fundamental to the basic assessment of compatibility of NVIS lighting with night vision goggles is the concept that nothing in the cockpit should appear brighter (when viewing through the NVGs) than the external scene. For this baseline it was assumed that the external scene was illuminated/irradiated at a clear starlight level and was reflecting from material having the spectral reflectivity of tree bark. When this spectral distribution was weighted by the spectral sensitivity curve of the NVGs (so-called Class A NVG – see Mil-L-85762A for spectral sensitivity of both Class A and Class B NVGs) and integrated across all wavelengths, it provided a radiance of $1.7 \times 10^{-10}$ watts/cm$^2$-sr. Later, NVGs with a different objective lens coating were designed, designated Class B NVGs. Class B NVGs have a slightly different spectral sensitivity in the red region of the spectrum. When the tree bark/starlight spectrum is weighted by the Class B NVG spectrum and integrated one gets $1.6 \times 10^{-10}$ watts/cm$^2$-sr. ASC/ENFC 96-01 Rev 1 dated 22 March 1996 (section 4.6.2) and NADC-87060-20 dated 17 September 1987 (page 17) state NVIS radiance should be no more than $1.7 \times 10^{-10}$ $NR_A$ for Class A NVIS and $1.6 \times 10^{-10}$ $NR_B$ for Class B. However, the NADC document calls these values out when lighting equipment is illuminated to produce 0.1 ft-Lambert luminance and the ASC/ENFC document uses these values for the visual acuity assessment. Mil-L-85762A and ASC/ENFC 96-01 both provide tables, however, that call for a maximum radiance of $1.7 \times 10^{-10}$ NR for either Class A or Class B NVG when the luminance is set to 0.1 ft-Lambert. The visual acuity evaluation procedures called out by AFRL/HEA (Appendix A) also uses $1.7 \times 10^{-10}$ NR for either Class A or Class B NVG visual acuity assessment. Regardless of these minor differences, the concept is that no light in the cockpit, when set to its specified luminance, should exceed the specified NVIS radiance limit. This original concept (nothing in the cockpit should be brighter than the external scene under clear starlight) has been significantly modified as evidenced by the plethora of allowed NVIS radiance values for various cockpit light sources. Regardless of the rationale for these modifications, the NVIS lighting system was deemed to be compatible if all of the light sources in the cockpit, when set to their specified brightness (luminance) level, did not exceed the specified radiance (as weighted by the Class A or Class B NVG curve as appropriate).

In order to verify that the NVIS lighting was compatible according to the defined luminance/radiance values it is obviously necessary to have photometric and radiometric equipment capable of measuring the luminance and radiance values. Portable equipment of this nature is expensive, not easy to use in the field, and/or not very accurate. For purposes of this research effort there is no inexpensive, commercially available equipment suitable to making these kinds of measurements in the field. The following is a sample list of devices that have been or could be used and the associated capability and cost.

**NVG 103** - Hoffman Engineering, measures NVIS radiance, $20,000

**PR 1530 AR** - Photo Research, measures NVIS radiance, $28,000+

**Minolta LS-100 Photometer** - Minolta, measures luminance, $3,145

***Visual Acuity Assessment Baseline***

An alternative or additional method of assessing NVIS lighting compatibility is to conduct a visual acuity degradation inspection. This methodology is described in various references (Mil-L-87762A, Mil-Std-3009, ASC/ENFC 96-01, RTCA/DO-275). Appendix A contains the current NVIS lighting evaluation methodology description as practiced by AFRL/HEA (night vision training research team, Mesa, AZ). The following elements are required to conduct this baseline visual acuity assessment as described in Appendix A and/or the other listed references.

**Visual Acuity (VA) Chart –** Visual acuity is assessed using 1951 USAF Tri-Bar Chart with a photopic modulation (Michelson) contrast of 70%. This chart was acquired from Rochester Institute of Technology and is no longer available. However, 1951 USAF Tri-Bar Charts are available from Hoffman Engineering, (high, medium, low contrast) for $575 each.

**VA Chart Irradiance Source –** The USAF Tri-Bar chart is illuminated to a level of $1.7 \times 10^{-10}$ $NR_B$ on the white parts of the chart. A Hoffman Engineering LM-33-80A (available from Hoffman Engineering, $5,000) is used to illuminate (irradiate) the chart.

**VA Chart Irradiance Verification Equipment –** A Pritchard PR 1530-AR spot radiometer with a Class B filter is used to set the above noted radiance on the white part of the VA chart. This spot radiometer is available from Photo-Research for about $28,000 plus, depending on options. The radiance of the chart is then monitored using an NVG 103 inspection scope (available from Hoffman Engineering for $20,000).

**Evaluation Facility "Darkness" Verification –** The referenced documents state that the evaluation is "conducted in a darkened hangar, which is sufficiently light-tight to prevent undesired or outside light sources from interfering with any of the measurements." There are no quantitative means listed for verifying the test facility is sufficiently dark. However, if one cannot get the chart radiance low enough ($1.7 \times 10^{-10}$ $NR_B$) then it can be assumed the facility is not dark enough.

**Evaluator Characteristics –** Baseline methodology requires the evaluator be "trained" but there is no published documentation that defines the attributes or skills that one needs to have to be an evaluator. No certification system exists.

## ALTERNATIVE VISUAL ACUITY ASSESSMENT METHODOLOGY

This section of explores alternative equipment/methodology to conduct an NVIS lighting assessment using the visual acuity approach. The objective is to produce the same level of results (acceptance/rejection probability) as the baseline visual acuity described earlier but use much less expensive equipment. The following sections parallel the baseline section headings but describe possible alternative equipment/procedures to theoretically achieve the same results.

**Alternative Visual Acuity Chart –** The USAF 1951 Tri-Bar chart is currently available (for free) on the WEB in a PDF file format. This version of the chart, when viewed from a distance of 20 feet, provides visual acuity patterns (tri-bars) for Snellen acuities of about 20/90 and better. Since currently available NVGs are capable of about 20/50 Snellen acuity for the radiance levels noted above this chart should be able to serve as a suitable visual acuity chart. However, it should be printed on white bond paper using a laser printer to insure chart image quality. In addition, this chart prints out in high contrast (greater than 90%) unlike the 70% listed for the baseline chart. It may be possible to make this PDF file print out at lower contrasts or it may be that the difference in contrast levels will not significantly affect evaluation results.

Another alternative to the USAF Tri-Bar Chart PDF file is to use publicly available software (already supplied to the FAA) that was developed at AFRL/HECV that prints out square-wave grating patches for a wide range of Snellen acuities (selectable) and viewing distances (also, selectable). This grating chart maker (GCM) software could be used to produce a few well-chosen gratings that could serve as an appropriate visual acuity assessment chart. Again, the software currently prints these grating patches as high contrast (greater than 90%).

**Alternative Chart Irradiance Source –** The spectral distribution of the light source used to illuminate (irradiate) the visual acuity chart is not critical but there does need to be a way to verify that the VA chart is illuminated (irradiated) to the correct level (within reasonable accuracy). It has been determined that a 7 1/2 watt bulb in a bell shaped housing (an inexpensive, commercially available lamp), operating at 110 volts, with a 1/8 inch aperture in a thin, opaque baffle covering the bell housing, will provide the appropriate level of NVIS radiance at a distance of approximately 21 1/2 feet. However, if the evaluation facility has significant light leaks that provide some level of ambient illumination/irradiance on the VA chart, then a means must be provided to reduce the radiance level in a controlled fashion or the facility may need to be declared unsuitable for testing.

**Alternative Chart Irradiance Verification Equipment/Means –** If the facility proves to be dark enough (see section below) then there may not need to be any means to verify chart radiance directly. It may only be necessary to insure the 7 1/2 watt bulb is operated at 110 VAC using a volt-meter. Alternatively, it may be possible to use a volt-meter to determine the local line voltage and adjust the distance from the bulb to the chart using a pre-calculated conversion chart. Another alternative is to acquire an inexpensive light (illuminance) meter (about $120) and attach it to the eyepiece of the night vision goggle (NVG) that is to be used. It may then be possible to calibrate the combination of the NVG and the light meter using the 7 1/2 watt bulb illuminator at a specified distance in a completely dark (smaller) room. The NVG/light meter combination could then be used to verify the radiance level of the chart. Although this methodology is somewhat complex, it is theoretically doable.

**Means of Verifying Darkness Level of Evaluation Facility –** If the NVG/light meter procedure described above is fully successful then the NVG/light meter combination could be used directly to verify that the test facility is dark enough to conduct a valid evaluation. Alternatively, it is possible that a very low resolution visual acuity (such as 20/200) grating patch could be used. If this very low resolution patch is not resolvable through the NVGs with only ambient (facility light leaks) irradiation available, then the facility should be dark enough. It will be necessary to conduct a small amount of research to determine what the Snellen acuity should be for the grating patch, if this approach is used.

**Alternative Evaluator Characteristics –** The baseline assessment procedure states that the evaluator should be trained, but does not go in to any further detail. At a minimum, the evaluator should have a sound understanding of the basic operation and adjustments of the NVGs to be used and be familiar with possible lighting interference mechanisms. In addition, the evaluator should have sufficient knowledge of the specific evaluation methodology to be able to judge the validity of the equipment and procedures used in the evaluation. The visual acuity of the evaluator, when viewing through NVGs, should be capable of some minimum acceptable level. Selection and training criteria for an NVIS lighting assessment evaluator is not part of this research effort, but the above criteria/characteristics should be considered in selecting/qualifying an individual to be an evaluator.

## OBJECTIVE NVIS ASSESSMENT METHODOLOGY

The baseline NVIS lighting assessment methodology very clearly establishes an objective means to verify NVIS lighting acceptability. This includes previously described radiometric measurement equipment to measure the NVIS A or NVIS B radiance and photometric equipment to measure the luminance of the light source. The light source or display is deemed to be NVG compatible (acceptable) if the measured (or calculated) radiance is within permitted levels when the measured (or calculated) luminance is at the specified level. The problems with the baseline methodology are the high cost of the measurement equipment and the difficulty of using this expensive equipment for a field evaluation. In addition, the NVG 103 inspection scope designed for use in field evaluations is relatively inaccurate (on the order of +/- 30%).

Given the difficulty of using this expensive equipment to conduct field evaluations, it is unlikely that one can achieve comparable results with an inexpensive device. Ideally, one would like to have a very clear procedure and a device that would provide a very clear reading that could be translated to an unambiguous accept or reject decision. The following devices/procedures are possible approaches along the pathway to this non-existent ideal device.

### *NVG light output assessment method*

A relatively inexpensive illuminance meter ($120) has been identified that, when slightly modified, can be attached to the eyepiece of an NVG to provide a reading proportional to the light output of the NVGs. There are two possible approaches to using this device as an NVIS compatibility meter, which are described below:

**Absolute light level criteria –** For this approach the combination NVG and light meter must be calibrated so that output luminance values can be related to NVIS radiance values. The light meter is first modified by removing the cosine plate (diffuser plate) that covers the detector. This increases the sensitivity of the device so that it can be used to assess the light output of the NVG. The NVG/light meter combination is calibrated by pointing the NVG at a white, diffusely reflectively surface (TBD – perhaps a white bedsheet) that is illuminated by the previously described 7 1/2 watt lamp with 1/8 inch hole. The distance from the illuminator to the white reflective surface and the distance from the NVG/light meter to the white surface need to be appropriately specified distances (TBD during research). The reading obtained from the light meter during this procedure will be used to calculate a conversion factor that will allow one to convert the light meter reading to NVIS radiance.

The second step in this procedure is to position the calibrated NVG/light meter in the appropriate location in the cockpit pointed toward the outside. With the cockpit lights off, a reading is taken from the NVG/light meter – this is the baseline reading (a measure of the ambient lighting in the "dark" facility). Without moving the position of the NVG/light meter the cockpit lighting is turned on (it should have already been adjusted to an "operationally relevant" level). This provides a second reading from the NVG/light-meter. The first reading is subtracted from the second reading to provide an NVIS radiance value that is due to incompatible light in the cockpit. If this value does not exceed a (TBD) certain criteria value, then the light system is considered to be compatible. This same procedure is then repeated for other view directions out of the cockpit to verify there is no problem in viewing out of the aircraft in any relevant direction. Note that this procedure does not require an absolutely dark test facility since the baseline ambient level is subtracted from the cockpit lighting reading.

One caution when using this approach: a visual inspection using the NVG should be performed first to insure there are no objectionable direct reflections in the windscreen or canopy. Since the light reading is an average across the field of view of the NVGs, it cannot differentiate between a single, bright point source reflection (which might be visibly objectionable) and a large area dim reflection (which might be perfectly acceptable). It is apparent that there is still an element of subjective assessment using this device, even if it is considered fully successful.

**Relative light level criteria –** For this method it is not necessary to calibrate the NVG/light meter combination. A large reflective surface (e.g. white bedsheet) is positioned a specified (TBD) distance from the cockpit and illuminated with the 7 1/2 watt bulb illuminator (previously described) from a specified (TBD) distance. The NVG/light meter is then positioned in its operational location in the cockpit and pointed toward the reflective surface. A baseline reading is taken with all the cockpit lights off. Then the cockpit lights are turned on and a second reading is taken. The cockpit lighting is considered acceptable if the second reading is no more than (TBD) percent higher than the first reading. This indicates the incompatible lighting in the cockpit is providing only a small (TBD percent) amount of interfering light compared to the light from the external scene. The implication is the interfering light is negligible compared to the external scene light level (which will be in the vicinity of the clear starlight levels used for present visual acuity assessments of NVIS lighting). The same “bright source reflection caution” noted above also applies here.

***NVG objective lens irradiance method***

This approach uses the same light meter/NVG combination noted above. However, in this approach the objective lens of the NVG is capped with a diffusing plastic material, which acts like a cosine plate used for illuminance meters. The objective lens is adjusted for closest focus so that if there is any minor amount of light getting through the diffuser undiffused it will be defocused by the objective lens. The test is then conducted in a dark facility (level of darkness may be determined by the Snellen acuity chart method described previously). The NVG/light meter (with a diffuser over the objective lens) is positioned appropriately in the cockpit. A baseline reading is taken with all cockpit lighting off. Then all the cockpit lighting is turned on and a second reading is taken. The baseline reading is subtracted from the second reading. If this value is equal to or less than the specified value, then the cockpit lighting is considered to be compatible.

Note that this measurement combination also needs to be calibrated using a procedure similar to the one described previously, except that there is a diffuser over the objective lens in this approach. This approach provides a measure of the NVIS Irradiance at the surface of the objective lens of the NVG. This approach is less sensitive to reflections in the windscreen/canopy, but should be more sensitive to general light pollution in the cockpit. It is highly probably that the number readings obtained with this method will be more sensitive to positioning of the NVG/light meter combination.

## DISCUSSION/CONCLUSIONS

It is highly likely that the alternatives under consideration for providing the main elements needed to conduct visual acuity assessment will be successful resulting in much less expensive testing. However, the selection and training of the evaluators will still need to be addressed. The two objective assessment methods will probably be partially successful, but most likely neither one of them could be considered a complete, stand alone device for determining acceptance/rejection of the lighting system under test. No other alternatives have been submitted by any of the associated organizations. The other alternatives previously presented at the June 18, 2002 meeting in Washington DC are less likely to succeed than the ones presented here. Therefore, with the limited time and funding available, we plan on tackling the alternatives described herein as the ones that have the best chance for success.

## REFERENCES

ASC/ENFC 96-01 REV 1, (1996), Interface Document, Lighting, Aircraft, Interior, Night Vision Imaging System (NVIS) Compatible, 22 March 1996, ASC/ENFC, Wright-Patterson AFB, OH.

Inter-Agency Agreement DTFA01-02-X-02017 (February 2002) Between the Federal Aviation Administration (FAA) and the Department of Defense Air Force Research Laboratory (AFRL/HEC, Wright-Patterson AFB.

MIL-STD-3009, 2 February 2001, *Department of Defense Interface Standard for Lighting, Aircraft, Night Vision Imaging System (NVIS) Compatible*.

MIL-L-85762A, 26 August 1988, *Military Specification, Lighting, Aircraft, Night Vision Imaging System (NVIS) Compatible*.

Reising, J.D., Antonio, J.C., and Fields, B, (1995), *Procedures For Conducting A Field Evaluation Of Night Vision Goggle-Compatible Cockpit Lighting*, AL/HR-TR-1995-0167

Reetz III, Ferdinand (1987), *Rationale behind the requirements contained in military specifications MIL-L-85762 and MIL-L-85762A*, Technical Report NADC-87060-20, 17 September 1987, Naval Air Development Center, Warminster, PA.

RTCA/DO-275, October 12, 2001, *Minimum Operational Performance Standards for Integrated Night Vision Imaging System Equipment*, prepared by SC-196, Washington, DC.

## Appendix A

### STANDARD NVIS-COMPATIBLE COCKPIT LIGHTING EVALUATION METHODS

**AFRL/HEA NVG Training Research Team, Mesa AZ**
**August 12, 2002**

This document describes methods used by the Air Force Research Laboratory (AFRL/HEA), Mesa, AZ, to evaluate Night Vision Imaging System (NVIS) compatibility of aircraft cockpit lighting. The primary purpose of the cockpit lighting evaluation is to determine the conformance of the modified lighting systems of the aircraft with the requirements specified in ASC/ENFC 96-01, Lighting, Aircraft, Interior, Night Vision Imaging System (NVIS) Compatible. (ASC/ENFC 96-01 succeeds MIL-L-85762A for Air Force aircraft; the performance requirements contained in the two documents are identical.)

Four critical methods are chosen from ASC/ENFC 96-01 to assess compatibility: Daylight Readability, Nighttime Readability, NVIS Radiance, and NVG-Aided Visual Acuity. Cockpit lighting that conforms to the requirements set forth in these four areas is suitable for NVIS operations. The evaluation is conducted in a darkened hangar, which is sufficiently light-tight to prevent undesired or outside light sources from interfering with any of the measurements. Descriptions of the methods follow.

*AUTHORS' NOTE: Since the FAA AFRL/HE research effort deals only with lighting interference with the use of NVGs only the two sections of this document dealing with interference are included here (NVIS Radiance and NVG-Aided Visual Acuity).*

NVIS RADIANCE

ASC/ENFC 96-01 specifies that NVIS radiance (NR) be measured from the cockpit displays. NR represents the amount of energy within the spectral response range of the NVG. ASC/ENFC 96-01 establishes NR limit values to ensure that the cockpit lighting is no brighter than the outside scene during this operating condition, typically represented by a defoliated tree under clear starlight conditions. NR limit values are specified in Table IV of ASC/ENFC 96-01, and are established for both Class A ($NR_A$) and Class B ($NR_B$) NVGs. Any lighting that produces radiance greater than the appropriate specified NR value is incompatible by definition.

NVIS radiance is measured using a Hoffman NVG-103 Inspection Scope. The inspection scope contains an internal reference source that is adjusted to the NR limit value ($1.7 \times 10^{-10}$ NR as appropriate for Class A or Class B lighting systems) specified in ASC/ENFC 96-01. An intensified image of both the internal reference source and the scene of interest are visible in the eyepiece of the inspection scope. The cockpit lighting is adjusted to an operationally representative level by a dark-adapted individual familiar with the aircraft cockpit, and then scanned by the evaluator using the inspection scope to identify any light sources appearing brighter than the internal reference source. The radiance of any bright sources is measured. Because radiance measurement using the NVG-103 requires brightness matching, multiple measurements of any given bright source are taken, and measurements are performed by several observers if possible, to obtain a reliable value. The inspection scope is fitted with a Class A or Class B filter, as appropriate, when scanning for bright light sources.

To derive NVIS radiance values, ASC/ENFC 96-01 requires that the brightness of primary and secondary displays be adjusted to produce 0.1 foot-Lambert (fL), and the brightness of monochromatic electronic and electro-optical displays be set to produce 0.5 fL. However, during lighting evaluations the displays are adjusted to operationally representative levels that may or may not equal 0.1 fL, so their actual luminance values are measured with a photometer. ASC/ENFC 96-01 allows a scaling factor (specified luminance divided by measured luminance) to be used to adjust the NR value to match the operationally representative luminance. The scaling factor can influence the overall determination of NR. For example, a measured luminance greater than the specified luminance will produce a small scaling factor. When that scaling factor is multiplied by the measured NR, the result is a smaller overall NR value. Luminance measurements for this evaluation are obtained using a Minolta LS-110 spot photometer with a #110 close-up lens providing a measuring field diameter of 0.5 mm at minimum focus distance.

[Note: Scaling generally cannot be applied to back-lit LCDs, in which 'black' areas may exhibit very low luminance while at the same time emitting high levels of NVIS radiance. Besides assessing an operating LCD set to an operational brightness level that closely matches the baseline luminance value specified in ASC/ENFC 96-01, and exhibiting visible information (e.g., a test pattern), the radiance of the operating LCD exhibiting a blank dark background also should be assessed.]

NVG-AIDED VISUAL ACUITY

NVG-aided VA is assessed during NVIS compatible cockpit lighting evaluations. NVG-aided VA is assessed using an ITT F4949 equivalent NVG fitted with Omnibus-4 specification intensifier tubes and modified Class B ('Leaky Green') filters, providing performance representative of systems being procured by the Air Force. ASC/ENFC 96-01 specifies that a resolution target be illuminated such that $1.7 \times 10^{-10}$ $NR_B$ (for Class B NVGs) is reflected from the white portion of the target. NVG-aided VA measurements are obtained from a trained observer(s) seated in the cockpit with all lighting off and then with the lighting adjusted to an operationally representative level. No detectable degradation in VA due to the cockpit lighting should be observed. If degradation exists, the incompatible light source(s) should be identified. Note: If current operators of the airframe are using older Class A NVGs, NVG aided VA is assessed using both Class A and B NVGs.

NVG-aided VA data are obtained using a USAF 1951 Resolution Resolving Power Target (Tri-Bar) chart.[i] The chart is placed 20 feet from the objective lenses of the NVG worn by the observer seated in the cockpit, as specified in ASC/ENFC 96-01. The chart consists of a large number of target elements, encompassing a wide range of sizes, divided into groups of six. The elements progressively increase in size (decreasing in spatial frequency) at relative intervals of $\sqrt[6]{2}$ (approximately 12%). Each element contains two patterns, each composed of three dark lines and separating white spaces all of equal width; one pattern is horizontal and the other vertical. Each group is identified by a different number, while the elements in each group are numbered 1 through 6. Due to the wide range of element sizes encompassed, a series of elements which brackets the resolution performance limit of a viewing device may be found at any reasonable fixed viewing distance. For a given viewing distance, the group/pattern numbers correspond to known Snellen visual acuity values (i.e. 20/20, 20/25, 20/45, etc.) varying at fixed intervals of approximately 12%.

During the evaluation, the chart is placed 20 feet from the objective lenses of the NVG worn by the trained observer seated in the cockpit. The chart is illuminated by a Hoffman LM-33-80 Starlight Projector. The illumination level is adjusted so that NVIS radiance measured from the white portion of the chart is equivalent to $1.7 \times 10^{-10}$ $NR_B$. This is measured with a Pritchard PR1530-AR spot radiometer with a Class B filter and verified with an NVG-103 inspection scope. If a second evaluation with Class A NVGs is required, the illumination will be adjusted to produce a target radiance of $1.7 \times 10^{-10}$ $NR_A$.

Prior to the assessment of NVG-aided VA, the trained observer(s) adjusts the NVG to obtain maximum VA with the chart illuminated to a level between 25% disc and full moon illumination. NVG-aided VA measurements in the aircraft are obtained from each observer seated in the cockpit under the following lighting conditions: 1) viewing forward through open air with all cockpit lighting extinguished, 2) viewing forward through the windscreen around the HUD combiner (if the aircraft is equipped with a HUD) and all cockpit lighting extinguished, 3) viewing forward through the windscreen and HUD combiner (if so equipped) with all cockpit lighting extinguished, and 4) viewing forward through the windscreen and HUD combiner (if so equipped) with the cockpit lighting (including the HUD) adjusted to an operationally representative level. The aircraft cockpit lighting is considered compatible if no degradation of NVG-aided VA is measured between conditions 3 and 4. The effect of windscreen transmissivity on NVG-aided VA is assessed by comparing NVG-aided VA between conditions 1 and 2. The effect of windscreen/HUD combiner transmissivity on NVG-aided VA also is assessed by comparing NVG-aided VA between conditions 1 and 3.

For each test condition, the observer views the chart with the NVGs and reports the group number and element number in which both the horizontal and vertical elements are barely resolvable. The observer is instructed that it is not necessary to see clear white spaces between the bars of each element, but they should be able to reliably count three bars and know their orientation.

**Appendix B**

**MIL-STD-3009**

# 5. VERIFICATION

## 5.1 System level verification.

**A** system level verification test of NVIS compatible interior lighting using visual acuity as the measure shall be done and can be outlined as follows. This test has been useful in determining that a contractor has met the NVIS system level requirements in a simple, straight forward, and quantifiable way.

a. Place aircraft with full-up NVIS interior lighting in an environment which is as dark as possible (e.g., a hangar with the doors shut, lights out, at night time, an engine hush house, etc.).

b. Place a visual acuity eye chart(s) a set distance from the nose of the aircraft where the pilot/copilot can see it (e.g., 6-10 m (20-30 feet)). Generally these charts have a high contrast (i.e., black on white) square wave pattern on them. Each chart has a different spatial frequency.

c. While looking through the NVGs that will be used operationally, have the test subjects read the charts as if taking an eye test and record their visual acuity scores. Do this with NVIS lights (only) ON as one condition and with all lights OFF as the other condition. The canopy should be closed.

d. This test shall be through the HUD and canopy (i.e., straight ahead) and off-axis (i.e., through canopy alone).

e. Compare the two visual acuity scores. If there is a significant difference/degradation in visual acuity between NVIS lights ON and lights OFF, then this may be due to an unacceptable level of NVIS incompatible light. Advise contractually pre-defining an acceptable, numerical visual acuity score.

f. Highly recommend contacting Air Force Research Laboratory (AFRL/HEA) at Mesa, AZ (formerly William AFB), DSN 474-6561 or 474-6120, for help with this test.

## Appendix C

Excerpts from SC-196 RTCA/DO-275 MOPS for NVIS equipment

### 4.4.1.2.2.5 NVG Visual Performance

The visual performance of the NVG must be assessed in order to determine that it meets the intended function. Although this is accomplished mostly during flight testing, ground testing will ensure that the NVG can be safely and effectively tested in flight, and is better suited for determining compliance with minimum standards.

If a test set is available that is compatible with the NVG, follow the recommended procedures for that test set and conduct an evaluation of the NVG. Typically this will include: gain, distortion, optical performance, cosmetic defects, collimation, etc.

If a test set is not available, a qualitative evaluation may be performed using a chart designed for NVG evaluations that is illuminated by a controlled photopic light source. The following is a recommended procedure:

1. Locate a space at least 30 feet long that can be made light tight (absence of light).

2. Place a 1951 USAF Medium or High Contrast Tri-Bar Chart (or equivalent tri-bar/sine/square wave chart) at one end of the space. The chart should contain vertical and horizontal resolution elements, and should be designed to be read at twenty-feet.

3. Illuminate the chart with a light source that is capable of producing selectable illumination that is reasonably equivalent to either full moon or starlight conditions. This can be a simple source and does not need to accurately represent the color content of the night sky. Refer to Appendix I for more information concerning light source setup and adjustment.

4. Stand twenty feet from the chart. After correctly aligning and adjusting the NVG, determine the smallest set of elements in which both horizontal and vertical lines can be discerned. It is not unusual to be able to more easily discern the vertical lines, but in order to be consistent, pick the smallest set in which both are discernable. Discernable means it is clear that the lines are

horizontal and/or vertical, but it does not necessarily mean that every individual line in the set can be seen.

*Note: Varying the illumination level and using charts with varying contrast levels will allow for more definitive testing of an NVG, and will help provide a better method of comparing the performance of two different NVGs.*

5. Note the findings and compare to the manufacturer's results for similar conditions (specification sheet). The purpose is to determine qualitatively if the NVG meets the minimum standards for resolution. See Appendix F for formulas that can be used to change resolution specifications into Snellen acuity figures.

6. In addition to resolution, other image characteristics should be assessed during this procedure. Be attentive to the presence of any of the following: dark spots, bright spots, honeycombing, edge glow, shading, and distortion. Should any of these be obvious and/or distracting, then compare to the minimum standards (Section 2.2.1.8) for compliance.

### 4.4.1.3.4.3 NVG-Aided Visual Acuity Evaluation

NVG-aided visual acuity (VA) measurements are obtained with the evaluator seated in the cockpit and with the cockpit lighting adjusted to an operationally representative level. No detectable degradation in VA due to the NVIS lighting should be observed. If degradation exists, the incompatible light source(s) should be identified, except as noted in Section 4.2.1. The NVG used during the evaluation should be representative of the NVG planned for use in the aircraft. If the NVGs intended for operational use have fixed focus objective lenses, then for the purpose of this evaluation NVGs having variable focus objective lenses and overall performance (e.g., resolution, gain) otherwise equivalent to the fixed focus NVG shall be employed. The assessment must be conducted in a facility where the illumination level can be easily controlled.

NVG-aided VA measurements are obtained using a USAF 1951 Medium (or High) Contrast Resolution Resolving Power Target (USAF Tri-bar Chart) or equivalent sine or square wave grating bar chart. The chart consists of a large number of target elements, encompassing a wide range of sizes, divided into groups of six. The elements progressively decrease in size (increasing in spatial frequency) at relative intervals of approximately 12%. Each element contains two patterns, each composed of three dark lines and separating white spaces all of equal width; one pattern is horizontal and the other vertical. Each group is identified by a different number, while the elements in each group are numbered 1 through 6. For a given viewing distance, the group/pattern numbers correspond to Snellen visual acuity values varying at fixed intervals of approximately 12%.

At least two experienced evaluators should be used for the evaluation. The chart is placed twenty feet from the eyepoint of the evaluator seated in the cockpit. If it is not possible to locate the chart at twenty feet (e.g., multiplace aircraft with various eye positions), the chart is placed at a position where it can be viewed while seated at all crew stations (mathematical adjustments can be made for the varied distances). More than one chart could be used if measurements are to be taken through different transparencies (e.g., windscreen, windows, canopy, etc.), through transparency reflections, or for other purposes. The illumination level on the chart should be adjusted so that NVIS radiance measured from the white portion of the target is equivalent to $1.6 \times 10^{-10}$ $NR_B$.

Prior to the assessment of NVG-aided VA, the evaluators will adjust the NVG to obtain maximum VA for the distance to the chart(s). If charts are located at different distances, it may be necessary to make small adjustments of the NVG objective lens focus for each chart. If the NVG has a diopter adjustment, care should be taken not to readjust the diopter setting when making these small adjustments for distance. While measurement conditions will be specific to the aircraft type, test procedures are usually performed in the following order:

1. Unobstructed (over or around all transparencies)

2. Baseline condition: View the chart through the appropriate transparency with all cockpit lighting extinguished, and note the smallest discernable element. Some transparencies may block near-IR energy, thus reducing the amount of energy to which the NVG is most sensitive. Any loss of VA noted when going from the Unobstructed Condition to the Baseline Condition is a result of this effect. In this event, the loss of NVG-aided VA should be assessed for potential adverse effects on flight operations. The NVG-aided VA noted during the Baseline Condition will be the comparison point for determining if the modified lighting has an adverse effect on NVG performance.

3. Trial condition 1: View the chart through the appropriate transparency with the cockpit lighting at an operational brightness level and note the smallest discernable element

4. Trial condition 2: View the chart through the appropriate transparency with the cockpit lighting at an operational brightness level and all warning, caution and advisory lights illuminated, and note the smallest discernable element.

5. If any VA degradation is noted between the Baseline Condition and either of the Trial Conditions, then additional measurements should be made with individual lighting components or combinations of components illuminated to identify the offending source(s).

6. Using the reflection information gathered during the nighttime readability assessment, view through adverse reflections with the NVG to determine the impact on NVG-aided VA. This may require the relocation of existing charts or the placement of additional charts. If a chart location is modified or if new charts are added, be sure to measure the viewing distance to the NVG. In addition to the reflections that are incompatible to the NVGs, evaluate the impact of reflections on unaided viewing. This may be difficult to adequately assess given the testing conditions. In that case, further evaluations should be conducted during flight tests.

7. If the aircraft is equipped with a windshield anti-ice system, it should be evaluated (if possible) to determine the impact on NVG use. Typically the problem will be distortion of the area being heated, which may cause some degradation of the outside scene when viewing through the affected area unaided or when using NVGs. The resolution chart should be viewed through the affected area to determine if there is any NVG-aided VA loss in addition to the distortion. The effects should also be evaluated during flight test to determine the impact to operations, and, if necessary, relevant procedures should be developed and incorporated into applicable aircraft manuals. CAUTION: When testing the anti-ice system, be sure to review operating limitations for the system. Damage to the windshield can occur if the system is actuated inappropriately.

## Appendix D

Excerpt from June 18, 2002 meeting minutes

From June 18 FAA meeting minutes:

Task presented four alternative techniques (1) modified MILSTD 3009 NVG aided visual acuity assessment, (2) NVG light output measurement sequence, (3) subjective luminance comparison, and (4) subjective luminance comparison version 2. Task stated that MILSTD 3009 and AFRL/HEA visual acuity procedure equipment cost is approximately $65,000 which is unacceptable for the FAA. Task's modified visual acuity method reduced equipment cost to approximately $3,000 but tests need to be conducted to determine whether this approach is valid and reliable. Task stressed that the AFRL/HEA visual acuity procedure will be used as the baseline to compare alternative techniques. If this method is not the baseline, then what is the alternative?

Although not required in ASC/ENFC 96-01, the compatibility of HUD imagery and the NVG may be assessed in aircraft equipped with HUDs. If required, the following two methods are performed in addition to the four critical test methods previously described. These tests are of particular interest in aircraft in which Forward Looking Infrared (FLIR) imagery is displayed on the HUD and viewed with NVGs.

[i] The USAF 1951 Tri-bar Chart was obtained from Rochester Institute of Technology and has a photopic modulation contrast of 70%.